SRHU JOURNAL OF ADVANCED RESEARCH

# Breath-based intervention in ischemic stroke rehabilitation: Clinical evidence and neurobiological perspectives

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**Keywords**

Alternate nostril breathing, diaphragmatic breathing, ischemic stroke, pranayama, stroke rehabilitation, yoga

**Abstract**

Non-motor impairments such as cognitive dysfunction, fatigue, and impaired quality of life resulting from ischemic stroke rehabilitation constitute significant challenges beyond physical recovery. The breath-based interventions represent a cost-effective and easily accessible complementary intervention, yet the therapeutic utility and neurobiological underpinnings of stand-alone breath techniques remain unclear relative to multi-faceted mind-body interventions, e.g. yoga. This paper reviews the clinical and translational studies investigating breathing techniques, including diaphragmatic breathing, unilateral nostril breathing, alternate nostril breathing (Nadi Shodhana), and Bhramari pranayama, in different domains of post-stroke recovery. The specific evidence for stroke patients confirms the significant positive effect of diaphragmatic breathing on the measures of pulmonary function, while there is some evidence on the selective benefit of unilateral nostril breathing on language and attention from repeated-measures designs. The functional and cognitive benefits provided by multi-component yoga intervention preclude the identification of the specific therapeutic value of breath control. The neurobiological mechanisms associated with breath regulation include autonomic balance, BDNF concentration, and cytokines but have been studied mainly in healthy volunteers or non-stroke populations. Whereas isolated breathing practice is an approach that is physiologically based and feasible in stroke rehabilitation, there is a lack of adequate clinical evidence on cognitive function, fatigue, and patient outcomes. It is important for future studies to focus on performing randomized controlled trials on isolated breathing exercises while simultaneously assessing biomarkers.

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Received: 8 August 2026, received in revised form: 17 August 2026, accepted: 21 September 2026, available online: 28 September 2026; Volume: 1; Issue: 3; Pages: 139-150.

**Citation:** Thakuri, S., Sharma, A., Bhat, A., Bhat, K., Gauniyal, S. 2026. Breath-based intervention in ischemic stroke rehabilitation: Clinical evidence and neurobiological perspectives. SRHU J Adv Res. 1(3): 139-150.

**DOI:** [to be assigned]
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## 1. Introduction

Stroke is among the most prevalent diseases globally, which leave the victims with major disabilities and unfavorable outcomes (Lazaridou et al. 2013). Amongst all, Ischemic Stroke makes up about 90% of cases and is commonly associated with high mortality rates and development of lasting stroke complications (Ademoyegun et al. 2025). It involves the deprivation of oxygen and nutrients in the brain for four minutes in an area called the "core" which usually happens due to a process called embolism where a blood clot within a blood vessel from other parts of the body travels to the brain initiating a cascade of cellular, metabolic and inflammatory responses (Kuriakose and Xiao, 2020; Majumder, 2024). Consequences of ischemic stroke do not limit to the initial neurological injury but might encompass persistent problems associated with motor function, cognition, and functional difficulties (Chan et al. 2012). Post-stroke cognitive impairment is an important component of this burden as it affects about 53.4% of stroke patients and different cognitive functions such as attention, memory, functioning and language (Mishra et al. 2024). As cognitive functioning plays a significant part in the performance of most activities of daily living, quick improvement in cognitive functioning is considered as one of the essential aspects of stroke rehabilitation (Kang et al. 2022). Post-stroke fatigue is another clinical implication resulting from stroke and can have a negative effect on physical activity as well as motivation (Aali et al. 2020). The combination of cognitive deficits, fatigue, and physical disability makes up a complex rehabilitation challenge that cannot be defined merely in terms of motor deficits. Similarly, neuroinflammatory reactions and alterations due to neural damage and healing processes also occur within the biological milieu of ischemic stroke. The process of neuroinflammation includes an activation of immune and glial processes as well as a number of inflammatory agents due to ischemia of the brain. However, neuroplastic changes are also relevant to the healing process since functional and synaptic adaptations play a role in brain damage recovery (Kashyap et al. 2023; Zhu et al. 2022). As a result, interventions that are easy, available, and able to be combined with traditional rehabilitation might have clinical importance when they can affect multiple aspects of recovery after stroke. Practices involving breathing fit into this category as they can be done with fairly minimal physical effort and can be easily combined with rehabilitation procedures (Kang et al. 2022; Shetty et al. 2020). The effects of breathing exercises in stroke patients have been investigated with regard to respiratory and to some degree cognitive functions. In a literature review on breathing exercises in relation to cognitive function in stroke, it was found that the research evidence showing possible cognitive effects of these breathing exercises is quite heterogenous, and the mechanisms of these effects have not been sufficiently understood yet (Kang et al. 2022). This suggests the importance of differentiating between the possibility of the breathing interventions influence and evidence of their efficacy.

The effects of yoga interventions have also been studied in stroke rehabilitation. Nevertheless, most of the yoga interventions used include breathing along with other components like asana, meditation, relaxation, etc. Hence, the effect that results from using

a yoga intervention will not be specific to breathing (Kashyap et al. 2023). This becomes especially relevant in the context of breathing as an independent element of treatment. Treatment that involves only breathing allows one to distinguish the physiological impact of respiration from that of body postures, asana, or meditative states (Kang et al. 2022). This literature review is thus centred on breathing interventions for stroke rehabilitation with regard to their clinical efficacy as well as possible neurobiological significance.

## 2. Ischemic stroke and the need for adjunctive rehabilitation approaches

### Non-motor consequences of ischemic stroke

Ischemic strokes can cause a range of effects involving motor, cognitive, emotional, and functional impairments that continue after the initial event. Cognitive impairment and fatigue are especially important since they may still be clinically significant after addressing physical issues through traditional forms of rehabilitation. There has been a lot of literature on post-stroke rehabilitation which has traditionally emphasized the issue of physical and motor recovery. However, the multifactorial effects of stroke necessitate rehabilitation that addresses cognitive issues, fatigue, and quality of life (Chan et al. 2012; Kuriakose and Xiao, 2020; Zhou et al. 2023). There is some evidence from yoga rehabilitation studies that alternative methods may be relevant in terms of these wider goals. However, it is hard to determine whether the breath plays a role in producing the effects based on the composition of interventions in previous studies. (Kashyap et al. 2023; Mishra et al. 2024; Schmid et al. 2012).

### Post-stroke cognitive impairment

Post-stroke cognitive impairment consists of deficits which develop following a stroke, and can be multidomain in nature. The Montreal Cognitive Assessment test was applied in stroke research for the evaluation of overall cognitive functioning across several domains. In their research into early yoga practice among stroke patients, Kashyap et al. have utilized the MoCA test, among other clinical and neuropsychological tests. They have found more improvements in MoCA and Frontal Assessment Battery scores in the yoga group in comparison to the control group at follow-up. Nevertheless, the intervention involved not only breathing practices but also strengthening and yoga postures as well. Consequently, this research shows the potential for impact on post-stroke cognition through the yoga rehabilitation program, but does not prove that breathing is the effective factor in this case (Kashyap et al. 2023).

### Post-stroke fatigue and quality of life

The presence of post-stroke fatigue is a constant challenge, which can influence the functioning and engagement of patients during their recovery process. The clinical relevance of the above factor justifies the need for incorporating fatigue as an outcome measure in assessing the effectiveness of any alternative rehabilitation strategies. Stroke-related fatigue is a reflection of the wide-ranging impacts of stroke on a patient's life, both physically, socially and emotionally. Therefore, the evaluation of an intervention designed for stroke recovery ought to include patient reported outcomes, like fatigue and quality of life (Chan et al. 2012; Zhou et al. 2023). However, current literature

concerning breathing has not provided enough evidence of its effect on fatigue and quality of life (Abdullahi et al. 2024; Kang et al. 2022). This represents an evidence gap rather than evidence of absence of effect.

**3. Breath-based interventions in stroke rehabilitation**

Breathing-based techniques include various types that vary according to breathing technique used, attention required, and unilateral or alternating nostril control (Kang et al. 2022; Marshall et al. 2014; Rajesh et al. 2014). In relation to the review being conducted, there are some important breathing practices or pranayama to be taken into consideration: diaphragmatic breathing, unilateral nostril breathing, nadi shodhana breathing and bhramari breathing (Abdullahi et al. 2024; Dhanaradja et al. 2025; Rajesh et al. 2014).

**Diaphragmatic breathing**

The diaphragmatic breathing technique involves controlled breathing with higher involvement of the diaphragm and is usually recognized as a respiratory rehabilitation method. Its impact on the rehabilitation process following stroke has been assessed primarily in terms of respiratory function. Shetty et al. compared the effects of diaphragmatic breathing exercise and incentive spirometry methods on respiratory function in stroke patients. This research shows that respiratory rehabilitation has certain relevance to respiratory function following stroke despite the fact that its methodology does not provide information on the impact on cognitive functions, fatigue or neurobiological recovery. Another systematic review and meta-analysis of the effects of diaphragmatic breathing on post-stroke recovery included six randomized controlled trials with 151 stroke patients and showed improvement in some respiratory parameters, such as forced vital capacity, forced expiratory volume in one second and peak expiratory flow. The researchers concluded that evidence on the efficacy of diaphragmatic breathing was more substantial for respiratory function than for other outcomes. Thus, diaphragmatic breathing can be regarded as an evidence base for the respiratory function in breathing-based rehabilitation after stroke (Abdullahi et al. 2024; Shetty et al. 2020).

**Unilateral nostril breathing**

Unilateral nostril breathing is especially relevant for the current study since it has been examined in stroke survivors. Marshall et al. have studied unilateral nostril breathing among 11 stroke patients in a repeated-measures experiment for 10 weeks. The research covered attention, language, spatial skills, depression and anxiety, and demonstrated some improvements in certain measures related to language. The research represents initial evidence about the possible effects of unilateral nostril breathing on cognitive functioning and language skills in stroke patients. However, its small sample and repeated-measures design prevent making strong inferences about its efficacy. It should be noted, however, that the research differs from evidence obtained from healthy subjects in that the intervention has been directly tested among patients who have had strokes. Nevertheless, the evidence should be regarded as preliminary and requires further confirmation (Marshall et al. 2014).

**Nadi Shodhana**

Alternate-nostril breathing, or Nadi Shodhana, is a breathing technique, which consists of alternating the airflow through one's nostrils (Dhanaradja et al. 2025; Mittal et al. 2025). The possible connection of alternate-nostril breathing with the field of neurological rehabilitation can be proved based on the scientific research into cognition, autonomic function, and quality of life in neurological patients. According to Dhanaradja et al. (2025), a randomized controlled trial of 12-week alternate-nostril breathing performed as an adjuvant therapy in people suffering from mild-to-moderate Parkinson's disease demonstrated a positive influence on the patient's cognition, cardiac autonomic function, psychological state, and quality of life. The results are important for considering alternate-nostril breathing as an intervention technique for neurological disorders but cannot be directly applied to ischemic stroke, since these two diseases have different physiological features. Therefore, the connection of Nadi Shodhana with the treatment of ischemic stroke is a question for further research (Dhanaradja et al. 2025).

**Bhramari Pranayama**

Bhramari pranayama involves humming during exhalation and has been studied in association with cognitive control and brain responses. The effects of Bhramari in terms of cognitive control were investigated in a study carried out by Rajesh et al. who found significant changes in response inhibition after Bhramari practice. Thus, the relationship between Bhramari and cognitive control has some experimental support but no studies have looked at stroke survivors yet (Rajesh et al. 2014). In turn, Upadhyay et al. reviewed the possible association of Bhramari with brain activity and underlined the necessity to investigate the neurocognitive impact of Bhramari in clinical settings (Upadhyay et al. 2023). Hence, the evidence currently available may be considered interesting from a mechanistic perspective but not clinical.

## 4. Clinical evidence for breathing-based interventions in ischemic stroke

**Direct breathing-specific evidence**

The study of unilateral nostril breathing carried out by Marshall et al. is one of those few studies that directly examined a breathing technique on post-stroke subjects. Improvements in language and verbal fluency in particular may indicate some cognitive benefit but further verification is required through large-scale controlled trials (Marshall et al. 2014). Diaphragmatic breathing has also been directly researched following strokes, however, to date, research in this area has been limited to respiratory benefits (Shetty et al. 2020). In the systematic review and meta-analysis, the most definitive evidence was found related to respiratory outcomes (Abdullahi et al. 2024). In summary, there is some direct evidence supporting the possibility of a breathing-based approach in the rehabilitation of post-stroke patients.

**Evidence from multicomponent yoga interventions**

The difference between breathing-specific and multicomponent interventions is important for the interpretation of yoga-related studies (Kashyap et al. 2023; Mishra et al. 2024; Schmid et al. 2012). According to Kashyap et al. (2023), yoga intervention which

included breathing techniques, strengthening exercises, simple postures, pranayama and meditation improved cognition in a period of six months. As different components of treatment were administered at once, it is impossible to identify whether breathing contributed to cognitive improvement. In their study Schmid et al. assessed yoga-based rehabilitation in patients with chronic stroke by means of modified postures, breathing and meditation and measured the following parameters: balance, balance self-efficacy, fear of falling and quality of life. Thus, the study presents information about rehabilitation based on yoga, not breathing (Schmid et al. 2012). Moreover, integrated yoga and naturopathy intervention studies described functional and cognitive results after stroke, however, the inclusion of several components makes it impossible to attribute observed changes to breathing (Mishra et al. 2024). Thus, multicomponent yoga studies serve only as context for further examination of breathing effects and cannot be used instead of breathing-specific randomized controlled trials.

## 5. Neurobiological relevance of breathing-based interventions

### Respiratory and autonomic regulation

Stroke can lead to deficits in respiratory muscle strength and pulmonary performance; hence, respiratory rehabilitation is critical for post-stroke recovery (Shetty et al. 2020). Diaphragmatic breathing has been linked with improved respiratory function in stroke patients, implying its physiological relevance to rehabilitation (Abdullahi et al. 2024; Shetty et al. 2020). In addition to respiratory mechanics, breathing can affect autonomic regulation due to variations in respiratory rhythm and parasympathetic tone. According to Hamasaki, diaphragmatic breathing involves autonomic and cardiovascular effects, thus offering a biological explanation for the study of breathing control for neurorehabilitation purposes (Hamasaki, 2020). Nevertheless, autonomic responses that have been observed in non-stroke subjects cannot be taken as proof of enhanced autonomic function in ischemic stroke subjects. Hence, autonomic regulation needs to be regarded as a possible pathway for recovery, which requires investigation.

### Breathing, cognition and neural recovery

Rehabilitation of cognitive functioning post-stroke requires various processes that work together to bring about the desired effects, and breathing can contribute to cognitive recovery through biological and psychological means. Kang et al. hypothesized that the link between respiratory exercise and cognitive functioning might occur via vascular, psychological, sleep and biochemical processes (Kang et al. 2022). The findings from unilateral nostril breathing serve as an initial indicator of the potential link between breathing exercises and certain language outcomes following a stroke (Marshall et al. 2014; Vanutelli et al. 2024). Clinical evidence is still sparse. In an experiment conducted by Marshall et al. there were some shifts in selected language and psychological parameters after unilateral nostril breathing in people with prior stroke history, thus providing indirect proof of the potential cognitive significance of breathing training (Marshall et al. 2014). Bhramari pranayama was found to have an association with response inhibition in healthy subjects, thus proposing the potential connection between

breathing control and executive cognition. Nevertheless, evidence obtained from healthy people cannot be considered direct evidence of the effects on cognitive recovery from ischemic stroke (Rajesh et al. 2014). Consequently, it gives some grounds to study if the application of structured breathing techniques can result in cognitive recovery after ischemic stroke.

**Neuroinflammation and recovery after ischemic stroke**

Neuroinflammation is one of the key elements in the biological response to ischemic stroke and includes interaction between immune, glial and other inflammatory mediator cells. In the course of the cerebral ischemia, different cytokines and interleukins can produce pro-inflammatory, anti-inflammatory or mixed effects, and their interactions may affect the process of injury development and recovery. Thus, the inflammation cannot be accurately described only with one cytokine and by pro-inflammatory and anti-inflammatory models. Instead, inflammatory response to stroke evolves over time and includes several interacting pathways that can have both injurious and reparative consequences. Such an approach to inflammation is important in the consideration of breathing exercises because any biological effects of the intervention should be discussed in the context of a broader immune response to stroke (Zhu et al. 2022). Mind-body interventions, for example, lead to alteration in the levels of inflammatory markers; however, such effects are not universal for all inflammatory mediators (Cahn et al. 2017). For instance, in their study, Cahn et al. found that IL-10 increased and IL-12 decreased after a three-month yoga and meditation retreat; however, some other inflammatory cytokines, such as IL-6, IL-8, TNF-α and IL-1β, were also observed to increase. This cannot be regarded as evidence supporting the effectiveness of breathing for inflammatory response modulation in patients with ischemic stroke, since the study involved a complex intervention of yoga, meditation, etc. in healthy individuals (Cahn et al. 2017). Consequently, the regulation of inflammation needs to be considered as a multidimensional biological phenomenon in further research.

**Neuroplasticity and neurotrophic processes**

Ischemic stroke recovery is associated with the adaptive response of neural networks in terms of synaptic and functional restructuring (Chang et al. 2024; Kuriakose and Xiao, 2020). Neurotrophic signaling is among these factors. BDNF has become a subject of particular research due to its involvement in neuronal viability, synaptic plasticity and cognitive recovery (Chang et al. 2024). Setyopranoto et al. found that lower serum BDNF levels were associated with impaired cognition after acute ischemic stroke, which highlights the relevance of BDNF as a biomarker of post-stroke cognitive recovery. Still, this correlation does not mean that BDNF serves as a mediator of cognition recovery (Setyopranoto et al. 2024). According to Cahn et al. changes in BDNF were observed after three months of yoga, pranayama and meditation combined for healthy subjects. Multimodal intervention and the lack of stroke population do not allow attributing those changes only to breathing (Cahn et al. 2017). Therefore, neuroplasticity and neurotrophic signaling serve as biological grounds for investigating breathing rehabilitation, but the link between breathing exercise,

neuroplastic changes and patient recovery has yet to be established.

Interaction between biological and clinical recovery

The consequences of stroke on the patients' clinical condition are complex in nature, and there may arise cognitive dysfunction, fatigue and decreased quality of life as well as neural and inflammatory damage. The framework for breathing-related rehabilitation should hence take into account the biological factors in relation to the patient-oriented outcomes and not regard the biomarkers as separate therapeutic targets (Cao et al. 2023; Kang et al. 2022; Setyopranoto et al. 2024; Zhu et al. 2022).The breathing techniques may have an effect on the above-mentioned recovery process via simultaneous impact on respiration control, autonomic regulation, psycho-emotional state and biology (Table 1) (Campanelli et al. 2020; Hamasaki, 2020). Nevertheless, the present literature does not show any clear causative chain from practicing breathing to a particular biomarker and then to the recovery process. This justifies the necessity of research where both clinical and biological outcomes will be considered simultaneously.

**Table 1. shows the evidence synthesis**

| S. No | Breath-based approach | Main domain investigated | Relevance to ischemic stroke | Major limitations | Study |
|---|---|---|---|---|---|
| 1 | Unilateral nostril breathing | Language, attention, anxiety and related outcomes | Provide direct preliminary evidence | Small sample and repeated-measures design | (Marshall et al. 2014) |
| 2 | Diaphragmatic breathing | Respiratory function | Supports the physiological relevance after stroke | Evidence mainly concerns respiratory outcomes | (Abdullahi et al. 2024; Hamasaki, 2020; Shetty et al. 2020) |
| 3 | Bhramari Pranayama | Response inhibition/cognitive control | Provide preliminary neurocognitive evidence relevant to the cognitive domain | Healthy participants rather than stroke survivors | (Rajesh et al. 2014) |
| 4 | Alternate Nostril Breathing | Cognition, autonomic balance and quality of life | Indirect evidence from neurological rehabilitation. | Population was Parkinson's disease rather than stroke | (Dhanaradja et al. 2025) |

| | | | | | |
|---|---|---|---|---|---|
| 5 | Breathing containing yoga | Cognition, balance, function and quality of life | Support the broader feasibility of yoga-based rehabilitation. | Breathing cannot be separated from other components | (Kashyap et al. 2023; Mishra et al. 2024; Schmid et al. 2012) |

**7. Discussion**

The existing literature indicates that breathing interventions might be relevant for ischemic stroke rehabilitation, although there are heterogeneity and differences in the evidence, depending on the intervention and outcome (Kang et al. 2022; Marshall et al. 2014; Shetty et al. 2020). There is direct stroke evidence on unilateral nostril breathing and diaphragmatic breathing, focusing mainly on certain language, psychological, and respiratory effects. This is useful information but is still insufficient to assess the usefulness of breathing as a rehabilitation tool. Information provided by the Bhramari and Nadi Shodhana techniques indicates the existence of possible cognitive and autonomic effects of breathing, although this evidence comes mostly from healthy subjects and non-stroke neurological patients (Dhanaradja et al. 2025; Rajesh et al. 2014). This is important information for formulating hypotheses but should not be equated to the evidence derived from ischemic stroke studies. There is also stroke evidence on yoga. According to Kashyap et al., patients showed improvement in their cognition after early practice of yoga, including breathing, strengthening, asanas, pranayama, and meditation, but it is difficult to attribute the observed cognitive effect to breathing (Kashyap et al. 2023). This limitation applies to other multi-component yoga studies as well (Mishra et al. 2024; Schmid et al. 2012). In terms of neurobiology, breathing could affect a number of processes important for recovery such as autonomic regulation, neuroinflammation, neurotrophic signaling, and cognition (Campanelli et al. 2020; Chang et al. 2024; Kang et al. 2022; Saini and Gurvendra, 2024). All of them are interconnected and not separate processes. Both autonomic and respiratory regulations could affect physiological states that affect cognition, while neuroinflammatory and neuroplastic processes could make up biological context in which stroke recovery occurs. The current evidence concerning BDNF and inflammatory markers could serve as rationale for biological assessment but it does not prove that these markers act as mediators for breathing. Cahn et al. noted changes in BDNF and inflammatory markers after practicing yoga, pranayama, and meditation, while Setyopranoto et al. showed clinical significance of BDNF for stroke recovery. Thus, these results could be considered as complementary evidence rather than proof of breathing-related effects (Cahn et al. 2017; Setyopranoto et al. 2024). The key research gap is low number of controlled studies that would focus on breathing and would exclude other aspects of yoga practice at the same time and analyze cognitive and clinical results (Kang et al. 2022; Kashyap et al. 2023; Marshall et al. 2014). Future research trials should include both analysis of structured breathing along with usual rehabilitation programs and analysis of their clinical outcomes along with relevant physiological and biological factors.

**Conclusion**

Interventions using breath control appear to be one of the least expensive and most physiological options for an adjunctive method of stroke rehabilitation. Direct clinical evidence has shown beneficial effects of breathwork on respiratory measures through diaphragmatic breathing, as well as possible effects on language and attention from more specific breathing methods, such as unilateral nostril breathing. However, meaningful conclusions concerning cognitive measures, post-stroke fatigue, and quality of life are limited due to small numbers of patients and diverse methodologies used, as well as the lack of distinction between pure breathwork and more complex yoga practices. Biologically, breath control seems to provide a reasonable way of neurorehabilitation through autonomic mechanisms, neurotrophic factor up-regulation (particularly BDNF), and systemic inflammation control; however, there is no solid proof of direct biomarker-related causality in humans with stroke. Further scientific investigation in this area should involve randomized controlled trials with sufficient power, which should include evaluation of isolated breath control practice together with neurorehabilitation methods using patient- and biological-related endpoints.

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